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Implementation and Performance Analysis of Multi-GNSS Signal Collection System using Single USRP

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ABSTRACT

In this paper, a system that can collect GPS L1 C/A, GLONASS G1, and BDS B1I signals with single front-end receiver was implemented using a universal software radio peripheral (USRP) and its performance was verified. To acquire the global navigation satellite system signals, hardware was configured using USRP, antenna, external low-noise amplifier, and external oscillator. In addition, a value of optimum local oscillator frequency was selected to sample signals from three systems with L1-band with a low sampling rate as much as possible. The comparison result of C/N0 between the signal collection system using the proposed method and commercial receiver using double front-end showed that the proposed system had 0.7 ~ 0.8dB higher than that of commercial receiver for GPS L1 C/A signals and 1 ~ 2 dB lower than that of commercial receiver for GLONASS G1 and BDS B1I. Through the above results, it was verified that signals collected using the three systems with a single USRP had no significant error with that of commercial receiver. In the future, it is expected that the proposed system will be combined with software-defined radio (SDR) and advanced to a receiver that has a re-configuration channel.

Keywords: USRP, GNSS signal, front-end, Software-Defined radio

1. INTRODUCTION

There are several global navigation satellite systems (GNSS). For example, not only global positioning system (GPS) run by the USA but also Galileo run by the EU and GLObal Navigation Satellite System (GLONASS) (GLONASS ICD 2008) by Russia as well as BeiDou Navigation Satellite System (BDS) (BeiDou ICD 2013) by China are operated currently. Each of the above satellite navigation systems employs a different modulation technique such as Binary Phase Shift keying (BPSK), Quadrature Phase Shift Keying (QPSK), or Binary Offset Carrier. It also employs a different multiple access technology such as Code Division Multiple Access (CDMA) and Frequency Division Multiple Access (FDMA). It also uses different Pseudo Random Noise (PRN) code, chip rate, carrier frequency, and signal's bandwidth. Accordingly, it is necessary to have a receiver suitable for each different communication technology to receive signals modulated with different methods. However, it is not advantageous to cope with signals from various navigation systems using a hardware receiver in terms of economic viewpoint. This is why SDR (Software-Defined Radio) has been studied to cope with multi-systems and multi-band signals based on software (Principe et al. 2011).

The SDR refers to a type of receivers that demodulate digital signals sampled and quantized through Analog to Digital Converters (ADCs) via software using general purpose processors (Borre et al. 2007). Since demodulation is done by a general purpose processor, even if signals whose modulation mode is different are inputted, a flexible response can be done by reconfiguring a channel with demodulation software that is matched with the corresponding signals. Furthermore, the reconfiguration technology used in SDR can be combined with cognitive radio so that it can produce a communication system that

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uses frequency resources efficiently (Reed & Bostian 2005). However, the front-end part that processes analog signals prior to the ADC is still dependent on communication systems. Therefore, a study on front-end that processes reconfigured channels flexibly has been conducted in parallel with research on SDR. As examples of typical technologies, direct RF conversion technology (Akos et al. 1999) that samples RF signals directly and a technique that utilizes a general purpose front-end can be found. Among them, the USRP (Universal Software Radio Peripheral) developed by Ettus is one of the widely known general purpose front-ends (Peng & Morton 2013). If the USRP is utilized, a Local oscillator (LO) frequency of mixer, gain of amplifier, and a sampling rate of ADC can be set to preferred values so a single piece of hardware can cope with various signals. Because of this advantage, the USRP has been much utilized in studies on SDR. For example, Purdue University (Thompson et al. 2012) and Virginia Tech (Peng & Morton 2013) also utilized USRP in studies on GNSS SDR.

A Purdue University research team configured a front end based on USRP in consideration of GPS signals only. In the USRP, external oscillator, down converter, amplifier, and band pass filter were additionally employed. Although GPS signal acquisition and track performance were verified, multi-system or multi-bands were not supported through the USRP. A Virginia Tech research team designed and implemented a system that collected GNSS signals of L1, L2, and L5 bands into two USRPs. They used each of the USPRs for each signal band and GPS and GLONASS were only considered out of the four GNSS systems.

Currently as of 2016, the BDS is operated with 19 satellites in Asia (BeiDou ICD 2013). Thus, it is necessary to have a signal collection system in consideration of the BDS in addition to GPS and GLONASS. Furthermore, a single front-end using a single USRP is needed to increase the effect of channel reconfiguration in SDR.

The present study designed and implemented a system that can acquire L1 band signals not only from the GPS and GLONASS but also from the BDS with a single USRP. It configured hardware by selecting antenna and amplifier in consideration of L1 band signals in the GPS, GLONASS, and BDS. In addition, it determined a LO frequency that minimized aliasing in consideration of USRP performance in order to acquire L1 band signals of three different systems as a single USRP. The GNSS signals acquired via the system implemented with the above method were quantized with 14 bit and stored in hard disks of personal computer (PC). Then, a method of well-known signal acquisition and signal tracking was implemented in the PC and received signals were processed. Here, C/N0 estimated during the signal tracking process and C/N0 of commercial receiver were compared thereby verifying the collected satellite signals.

2. INTRODUCTION TO GNSS SIGNALS

2.1 GPS L1 C/A Signal

GPS signals are serviced through L1, L2, and L5 bands. Among them, navigation data of L1 band signals are transmitted using the 1575.42 MHz carrier wave. A GPS signal of L1 band transmitted from the *i*-th satellite can be expressed as shown in Eq. (1) (Dunn 2012).

$$S_{L1}^{i}(t) = A_{CA}D(t)C_{CA}^{i}(t)\cos(2\pi f_{L1}t+\theta) + A_{P}D(t)C_{P}^{i}(t)\sin(2\pi f_{L1}t+\theta) \quad (1)$$

where D refers to navigation data, C_{CA}^{i} and C_{P}^{i} are the C/A code and P code, f_{L1} is a center frequency of GPS L1 signal, and θ refers to a phase. As shown in Eq. (1), L1 signal is represented as a type of signal that two signals spread via the two codes are added. Here, a terms where there is C_{CA}^{i} is the C/A signal and a term where there is C_{P}^{i} is the P signal. In Eq. (1), A_{CA} and A_{P} refer to signal powers that are spread by the C/A code and P code, respectively. Two signals have a power difference as much as 3 dB and A_{CA} is larger. Two signals have a phase difference of 90°. A publicly available signal among them is one that is spread by the C/A code. The C/A codes that have 1,023 chips generated by gold sequence method are used. The C/A codes are modulated with GPS L1 signals with 1.023 MHz of chip rate and spread to signals that have about 2 MHz of bandwidth. The signal collection system implemented in this study considers publicly available signals only. Therefore, the P code can be ignored because this study considered GPS L1 signals within only 2 MHz on the basis of 1575.42 MHz.

2.2 GLONASS G1 Signal

GLONASS operated by Russia transmits and receives signals modulated by the BPSK at G1 band of 1602 MHz. In contrast with GPS, it can transmit multiple satellite signals via the FDMA. The FDMA is a method to send signals by assigning a different carrier frequency by each satellite. In this method, all satellites use the same code without the need to assign different PRN code per satellite as the same as in GPS. The code of GLONASS G1 signal consists of 511 chips created via the M-sequence method and modulated with navigation signals at a chip rate of 0.511 MHz. The GLONASS G1 signal can be expressed as shown in Eq. (2).

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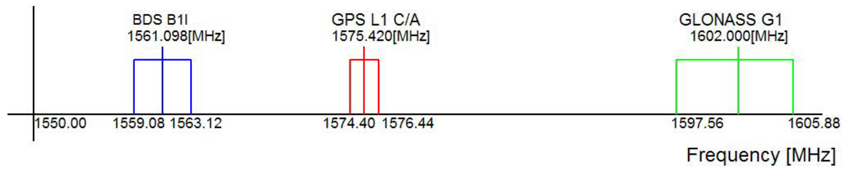

Fig. 1. Multi-GNSS signals in frequency space.

$$S_{g1}^{i} = A_{g1}C_{g}(t)[D(t)M(t)]\cos[2\pi(f_{G1} - 0.5625i)t + \theta_{g1}] \quad (2)$$

where A_{g1} refers to signal power, C_g is the GLONASS C/A code, D is navigation data, f_{G1} is a center frequency of the GLONASS G1 signal, and i refers to channel No. of the satellite. GLONASS satellites have their own unique frequency according to channel No whose range is -7–6. GLONASS assigns 14 channels to 24 satellites. It is operated to have satellites with the same channel to be placed at a symmetrical position around the earth (Glonass ICD 2008). One thing that is different from the GPS signal is that the navigation data signals are modulated one more time by a meander sequence. In Eq. (2), a meander is expressed with $M(t)$. A meander is 100 Hz signal where a sign of -1 and 1 is iterated. Due to the meander, a baseband signal obtained after signal tracking appears to have data at a rate of 100 bps.

2.3 BDS B1I Signal

The BDS is a satellite navigation system that is operated partially by China around Asia. It provides services via B1, B2, and B3 bands. Among the bands, B1 signal uses a similar frequency band with that of GPS L1 signal. B1 signal employs the QPSK modulation and consists of B1I and B1Q. However, only B1I is publicly disclosed. In this paper, only publicly disclosed signal is considered so that signals are received via the same method with the BPSK (BeiDou ICD 2013). Eq. (3) expresses the BDS B1 signal.

$$\begin{aligned} S_{B1}^{i} &= A_{B1I}C_{B1I}^{i}(t)[D(t)H(t)]\cos(2\pi f_{B1}t + \theta) \\ &\quad + A_{B1Q}C_{B1Q}^{i}(t)[D(t)H(t)]\sin(2\pi f_{B1}t + \theta) \end{aligned} \quad (3)$$

where A_{B1I} refers to B1I signal power, A_{B1Q} is B1Q signal power, C_{B1I}^{i} and C_{B1Q}^{i} are codes of B1I and B1Q signals, D is navigation data, and f_{B1} is a center frequency of BDS B1 signal. Since this paper considers disclosed B1I signal only, a signal in the first term is only considered. Its code is created using the same gold sequence method used in the GPS. The BDS B1I code consists of 11 shift registers, which is one more than that of the GPS in order to create 2046 chips. Currently, a total of 19 satellites is operated and CDMA technology of Direct Sequence Spread Spectrum that uses different PRN code is now applied.

In Eq. (3), H refers to the Neumann-Hoffman (NH) code. BDS B1I modulates 20 bit NH code, which has a period of 20 msec, together with the already modulated signal (BeiDou ICD 2013). Due to the NH code, data transition occurs every 1 msec after signal tracking and 50 bps navigation data can be synchronized by correlating the NH code.

2.4 GNSS Signals in L1 Band

GPS L1 C/A, GLONASS G1 and BDS B1I signals are called L1 band signals. These signals are present at 1.5 GHz band and distributed as shown in Fig. 1.

As shown in the distribution of Fig. 1, approximately, GPS L1 signal occupies 2 MHz band centered on 1575.42 MHz. The BDS B1I signal occupies 4 MHz band approximately considering the 1 dB bandwidth. GLONASS G1 occupies 8 MHz band approximately around 1602 MHz. In order to acquire the three signals at single front-end, a plan of IF-band frequency that can sample signals without band overlapping at a sampling rate as low as possible. Furthermore, hardware shall be configured by selecting antennas and external low noise amplifiers in consideration of the bands of the three signals.

3. IMPLEMENTATION OF SIGNAL COLLECTION SYSTEM

3.1 Configuration of Hardware

The following hardware was configured as shown in Fig. 2 to acquire signals of GPS L1 C/A, GLONASS G1, and BDS B1I simultaneously. For antennas, GPS-701-GGL of active mode from Novatel was used (NovAtel 2013). A 3 dB passband of GPS-701-GGL were 1588.5±23.0 MHz and 1545±20.0 MHz and attenuation characteristic as 30 dBc at ±150 MHz from the center frequency and 50 dBc at ±250 MHz was found. Signals found at around 1588.5 MHz included GPS L1 and GLONASS G1. Signals found at around 1545 MHz included BDB B1 signals. LNA was included inside the antenna,

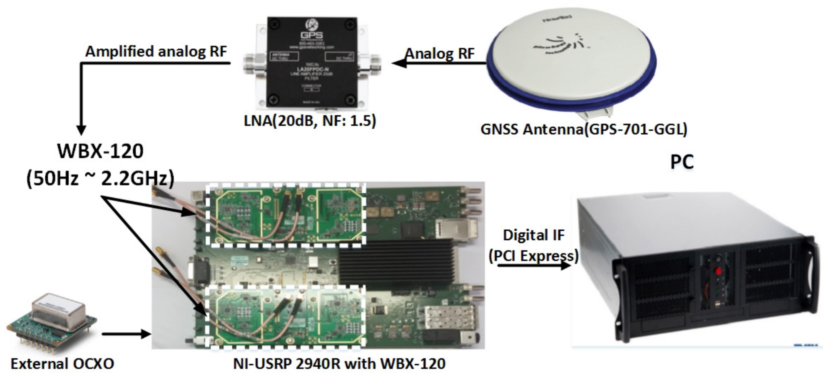

Fig. 2. Hardware configuration of USRP based signal collection system.

which had characteristics of 29 dB gain and 2.5 dB noise figure. For the RF signals incident at the antenna, signals within the passband were only inputted and transferred to the external LNA. The USRP did not support a function that removed a DC component separately during the active antenna use. An external LNA that can perform bias-T function and signal amplification was added to remove the DC component. The external LNA used had characteristics of 20 dB gain and 1.5 dB noise figure (GPSNETWORKING 2007).

The amplified RF signals were inputted via the USRP. The USRP used in this study was NI-USRP 2940R (National Instruments 2014). The USRP shall select a suitable daughter board to receive signals at a preferred band. WBX-120 among the daughter boards that can be usable in the USRP can receive signals in a bandwidth of 120 MHz only from 50 Hz ~ 2.2 GHz bandwidth (Ettus Research 2016). For the GNSS signal, signals of L1, L2, and L5 bands are present within the 1.1 ~ 1.7 GHz frequency band and a wide range of bandwidth is needed to receive a large number of signals. Thus, WBX-120 board is suitable to collect the GNSS signals.

The inputted analog RF signals are converted into digital IF signals through down converters and ADCs inside the USRP. Here, an amount of data in the digital IF signals increases proportionally with sampling frequency and the number of quantization bit. For the USRP, in-phase and quadrature-phase signals are sampled together and 16-bit or 32-bit per sample is stored (National Instruments 2014). If sampling is done at a rate of 100 mega sample per second (MSps) and 16-bit per sample is stored, signal data of 380 MByte per sec. are created. To support real-time transmission, an interface between PC and USRP requires a transmission rate above 380 MByte/sec. To achieve this, an interface of the Peripheral Component Interconnect (PCI) Express mode that is supported by the USRP is used. The PCI express supports 10 Gbit/sec of a transmission rate. Thus, the use of PCI Express can use the maximum sampling frequency of the USRP up to 200 MSps without limitation of PC performance. The digital IF signal is transferred to a PC through the PCI Express interface and stored as a file format.

The USRP has the internal oscillator of 10 MHz whose accuracy is 2.5 ppm (part per million). However, a Doppler error can be generated up to 4000 Hz at the L1 band signals if replica signals are created and down converted with the 2.5 ppm oscillator (Peng & Morton 2013). This problem increases a loop error of signal tracking thereby causing a performance degradation of receivers such as data error rate and navigation accuracy. To solve this problem, an external oscillator was added. The external oscillator is an Oven Controlled Crystal Oscillator compensated with GPS time information and can create a clock with 0.02 ppm accuracy (Ettus Research 2016). The 0.02 ppm accuracy could generate the maximum error of 30 Hz approximately for the L1 band. This error can be coped with in the GNSS signal tracking loop.

3.2 Frequency Plan and USRP Setting

In this section, IF and sampling rate determination for signal reception of GPS L1 C/A, GLONASS G1, and BDS B1I as well as USRP setup are described. The GNSS receiver employs a receiver structure of super-heterodyne that acquires baseband signals by lowering RF band signals into several MHz range IF signals in general (Borre et al. 2007). If this structure is employed, advantages such as frequency selectivity, sensitivity, and stability can be obtained with fewer element cost. When GNSS signals are received by using the USRP, LO frequency is controlled thereby acquiring RF signals lowered to preferred IF signals. Here, it is important not to overlap the each band of GNSS signals. Furthermore, if LO is set to minimize the maximum frequency of available signals, it can reduce computational

Table 1. Selectable sampling rate list in USRP.

Range	1~10 (MSps)	11~25 (MSps)	26~200 (MSps)
Selectable Sampling frequencies	1.00000	11.11110	28.57140
	2.00000	11.76470	33.33330
	2.98507	13.33330	40.00000
	4.00000	14.28570	50.00000
	5.00000	15.38460	66.66670
	6.06061	16.66670	100.00000
	6.89655	18.18180	200.00000
	8.00000	20.00000	
	9.09091	22.22220	
	10.00000	25.00000	

burden of SDR by reducing a sampling rate. In order to select an appropriate LO frequency, the maximum sampling rate that can be set due to the limitations of the USRP and PC performance was selected first. Next, LO frequency was selected not to overlap the signals in the three systems as much as possible by taking the maximum sampling rate and Nyquist-Shannon sampling theory into consideration.

Table 1 shows sampling rates that can be set in the USRP. Signals sampled at a usable sampling rate were received via the USRP and then stored in a PC. Then, the result showed that collection of signals sampled at a rate of 50 Msps was the limitation due to the PC performance used in signal collection in this paper. A specification of the PC used here was as follows: Intel i5-4690 (3.5 GHz), 8 GB RAM, and 1 TB of hard disk. If a sampling rate higher than 50 Msps was used, buffer overflow occurred because a time to record in the hard disk was slower than the signal data produced by the USRP. Moreover, in case of a sampling rate higher than 50 Msps, only 66.666 Msps, 100 Msps, and 200 Msps can be selectable thereby increasing a burden of SDR computation significantly. Thus, the maximum sampling rate was selected as 50 Msps and LO frequency was chosen in consideration of the maximum sampling rate.

A sampling rate is generally determined by a sampling theory of Nyquist-Shannon. If the inputted signal is one within the limited band, a sampling rate shall be twice the corresponding bandwidth in order to recover signals to the original signal. However, if the signal is not one found in the limited band as in this study, a sampling rate that is twice the maximum frequency shall be used. Since the maximum sampling rate is 50 Msps, the maximum frequency of the signal to be sampled shall be 25 MHz or lower to recover signals normally. Considering this, LO frequency was selected as 1584 MHz. The results are shown in Fig. 3.

Fig. 3 shows IF frequency and bandwidth of GPS L1 C/A, GLONASS G1, and BDS B1I signals when a LO frequency is set to 1584 MHz. Once RF signals of each system are down-converted through a mixer, the high frequency region is removed and only signals that belong to the difference of carrier frequency of each system and 1584 MHz remain. The center frequency is -8.58 MHz for GPSL1 C/A, 18 MHz for GLONASS G1, and -22.902 MHz for BDS B1I. Since negative frequency is not present if in-phase signals are only considered, the center frequencies of GPS L1 C/A signal and BDS B1I signal are +8.58 MHz and +22.902 MHz. However, if LO frequency is set to 1584 MHz, signals of BDS B1I and GLONASS G1 have an overlapping part of 1 M approximately. If a LO frequency is increased to make closer between GPS L1 C/A and GLONASS G1 to solve the above overlapping, the maximum frequency of BDS B1I is increased. Due to the limitation of PC performance and sampling rate of the USRP used in this paper, the maximum frequency cannot exceed 25 MHz. Thus, for a LO frequency, 1584 MHz where the maximum frequency of the signal is 24.92 MHz is the best selection.

Software that controls the USRP can be configured as shown in Fig. 4. If the NI-USRP is used, an application programming interface is provided for each of the functions

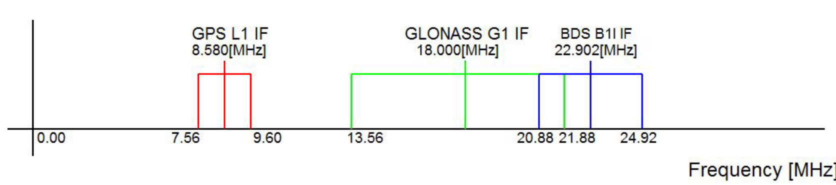

Fig. 3. Multi-GNSS signals in frequency space.

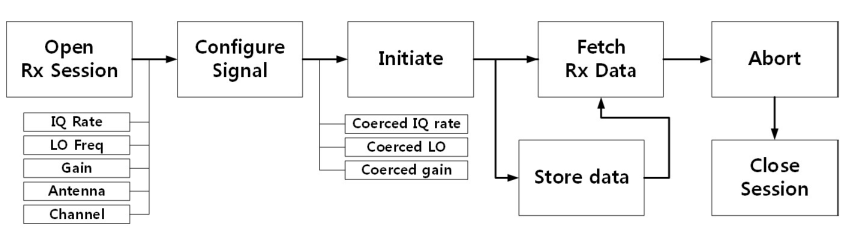

Fig. 4. A flow chart of GNSS signal collection system using USRP.

in the figure. In order to set a LO frequency and sampling rate that are designed in the above, the setup details are inputted to the configure signal block. The contents inputted to the configure signal block are IQ rate corresponding to a sampling rate, LO frequency, amplifier gain, and antenna terminal and channel where signals are inputted, which can be selected. Each of the setup values can be adjusted forcefully according to the performance in the USRP (Ettus Research 2016). The initialization is done based on the USRP setup information and then signal data are collected and stored according to the preset frequency. Here, data produced from the USRP are present in the form of in-phase signal and quadrature-phase signals in sequence. Each sample is 16-bit or 32-bit. In this paper, real signals are only considered and in-phase signals are only stored. Here, the quantization bit was 14-bit. The amplifier gain was 25 dB and each sample was stored as a size of 16-bit.

4. VERIFICATION

4.1 Signal Acquisition

A signal acquisition procedure is needed to verify the quality of signals acquired through the USRP. Signal acquisition is a process that searches code sequence in input signals, approximate code phase, and approximate Doppler frequency (Borre et al. 2007). Through this process, visible satellites at the current location is determined and signals are tracked. A method used in signal acquisition in this paper is parallel code space search acquisition (Borre et al. 2007). In this method, a correlation between code and input signal is performed in a frequency region thereby improving computation efficiency in the signal acquisition process and achieving fast computation.

The performance of the signal acquisition process varies according to signal length accumulated during the correlation computation. If only 1 msec-long signal is accumulated, satellites whose signal is weak cannot be acquired and comparison with commercial receivers can be difficult. In order to acquire signals of visible satellites sufficiently and compare the performance with that of commercial receiver, 5 ~ 20 msec-long signals are accumulated and signal acquisition operation shall be performed. The longer the time that accumulates signals is, the higher the signal reception sensitivity to weak signals is. However, with the increase in accumulation time, the Doppler frequency shall be searched more densely. This is because an interval b and accumulation time T of the Doppler frequency to be searched have a relationship of 2/3 $T>b$ (Kaplan & Hegarty 2006). If signals are accumulated at a 20 msec interval, the Doppler search shall be performed 20 times more than that at 1 msec. Thus, this study performed signal acquisition with accumulated signals as long as 5 msec considering the computation amount and visible satellite acquisition performance.

Table 2. Specification of signal tracking loop.

	PLL	DLL
Noise bandwidth (Hz)	25	2
Damping ratio	0.7	0.7
Integration time (sec)	0.001	0.001

4.2 Signal Tracking and C/NO Estimation

Once the type of signals included in the input signal and code phase as well as approximate Doppler frequency are searched through signal acquisition, navigation messages can be demodulated through the signal tracking process. Moreover, a carrier to noise ratio (C/N0) can be estimated based on the correlation value calculated in the tracking process. C/N0 is an important factor to compare performance between commercial receiver and designed signal collection system.

Signal tracking is divided into code tracking loop and carrier tracking loop. Typical methods used in each loop are Phase Locked Loop (PLL) and Delay Locked Loop (DLL) (Kaplan & Hegarty 2006). In this paper, these two methods were used and each loop was implemented using the specifications listed in Table 2.

A typical method that estimates C/N0 in the signal tracking process is Narrowband-Wideband Power Ratio (Falletti et al. 2010). This method calculates narrowband signal power and wideband signal power as shown in Eq. (4) using a correlation value I with the in-phase signal and a correlation value Q with the quadrature-phase signal.

$$P_{wide}^{k} = \left(\sum_{m=1}^{M} (I_m^2 + Q_m^2) \right)_k \quad , \quad P_{narrow}^{k} = \left(\sum_{m=1}^{M} I_m \right)_k^2 + \left(\sum_{m=1}^{M} Q_m \right)_k^2 \tag{4}$$

The narrowband signal power and wideband signal power calculated using M measured values are calculated iteratively K times and then a mean is calculated as shown in Eq. (5).

$$R_{n/w}^{k} = P_{narrow}^{k} / P_{wide}^{k} \quad , \quad R_{mean} = \frac{1}{K} \sum_{k=1}^{K} R_{n/w}^{k} \tag{5}$$

A ratio R_{mean} of mean signal power can be calculated with C/N0 using Eq. (6).

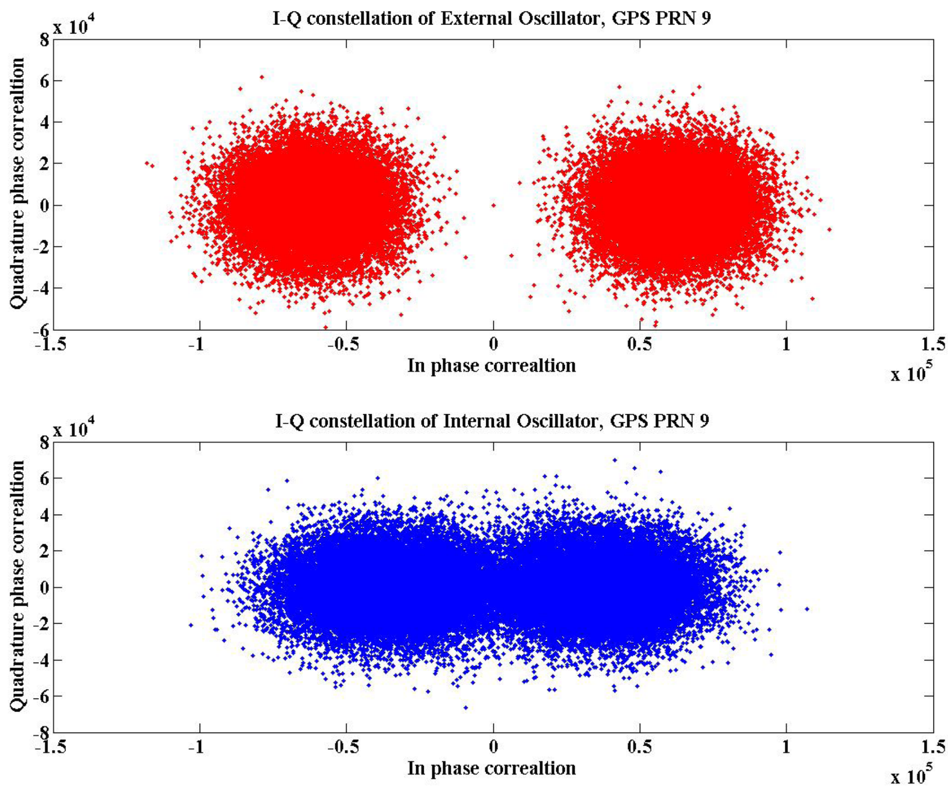

Fig. 5. IQ constellation of GPS L1 C/A PRN9 (up: using external oscillator, down: using internal oscillator).

$$C/N0 = 10\log\left(\frac{1}{T}\frac{R_{mean}-1}{M-R_{mean}}\right) \quad (6)$$

Since this paper sets M=20 and K=50, a measured C/N0 value can be obtained every second. Also, since an integration time of the signal tracking loop is 1 msec, it produces T=0.001.

4.2 Verification of Internal Oscillator and External Oscillator

It is not suitable to receive oscillator GNSS signals inside the USRP. To overcome this, an external oscillator whose performance was 0.02 ppm was added. In this section, GNSS signals were received using internal oscillator and external oscillator and signal tracking results were verified.

The experiment method is as follows. GNSS signals are acquired using an internal oscillator for 45 sec. approximately. Next, GNSS signals are acquired using an external oscillator for 45 sec. approximately. The signals acquired using the above two methods are stored in a PC and demodulated through the implemented signal acquisition and tracking module. Fig. 5 shows the IQ constellation graph as the result of No. PRN9 of GPS L1/C/A, which was demodulated into baseband signals, is divided into a case using internal oscillator and a case using external oscillator. GPSL1 C/A, which is BPSK, should be distributed into two groups as the same as in the external oscillator case if signals were demodulated normally. However, signal acquisition using the internal oscillator showed that two groups were overlapped around 0. If there is a circle that is overlapped between two groups in the IQ constellation, it means that a bit error occurs as much as the size of the overlapped circle. This experiment result showed that the internal oscillator in the USRP was not suitable to receive GNSS signals.

4.3 Comparison with Commercial Receiver

In order to evaluate performance of signal collection system of GPS L1, GLONASS G1, and BDS B1I designed by using a single USRP, measured C/N0 values were compared with those of commercial receiver. To have the same signal input to commercial receiver and the USRP, 2-way splitter after the LNA was added in the hardware configuration as shown in Fig. 2. The amplified GNSS signals are inputted to the USRP and commercial receiver through the splitter simultaneously. The commercial receiver used in this paper was Ublox-M8T (Ublox 2015). Ublox-M8T supports GPS L1 C/A, GLONASS G1, and BDS B1I as the same as the signal

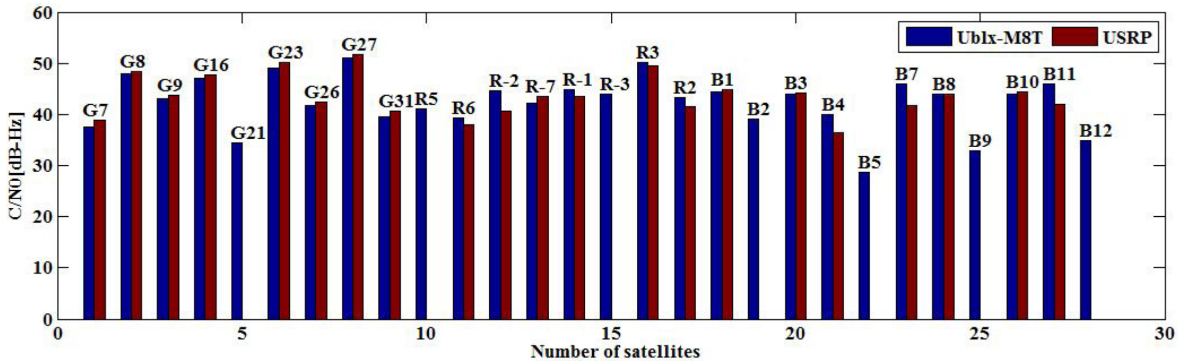

Fig. 6. C/N0 of USRP and Ublox-M8T on Jan 18, 2016.

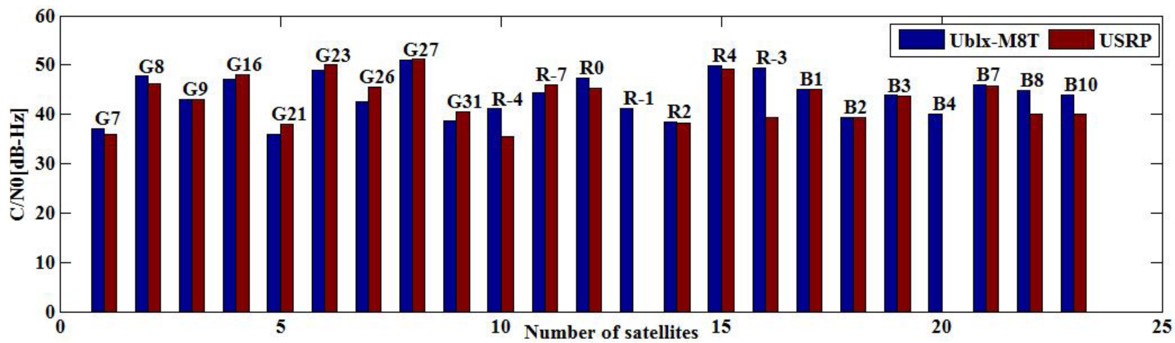

Fig. 7. C/N0 of USRP and Ublox-M8T on Jan 20, 2016.

collection system using the USRP. However, it was designed with double front-end structure to support three systems. Performances of double and single front-end structures can be compared by comparing Ublox-M8T and the designed signal collection system. However, Ublox-M8T cannot support three systems simultaneously and only supports either GPS and GLONASS or GPS and BDS one at a time. Thus, in order to obtain a measured C/N0 value of three systems, a reception mode, either GPS and GLONASS or GPS and BDS was shifted in every 30 sec. to collect the data. Two sec. or shorter time is required to receive signals of the corresponding system normally when reception mode is shifted.

The experiments were conducted twice at a different time. The first experiment results were signals obtained for three min. approximately at the roof of Education Center in Chungbuk National University on January 18, 2016. The second experiment results were signals obtained for three min. approximately at the same location on January 20, 2016. Measured C/N0 values in the commercial receiver were also recorded. Signal acquisition and tracking process were conducted with the collected signal using post-processing method and about 180 measured values of C/N0 were collected. Fig. 7 shows the comparison of C/N0 means of signals collected from two receivers on January 18, 2016.

Out of signals received using the USRP, seven signals were not acquired compared to that using Ublox-M8T. Signals that were not received here were weak signals below 35 dB-Hz except for GLONASS Nos. 5 and -3 and BDS No. 2. The other signals showed that a difference of C/N0 means of signals received through the USRP and Ublox-M8T was 0.5 dB, which indicated very similar results between them.

Table 3. Error of C/N0 about each system (Ublox-M8T is reference).

	GPS L1 C/A	GLONASS G1	BDS B1I
2016.01.18. (dB-Hz)	-0.837	1,263	1.755
2016.01.20. (dB-Hz)	-0.756	2.403	1.474

Fig. 8 shows a graph after the experiment of the signals acquired on January 20, 2016 using the same method as above. As shown in Fig. 8, the USRP acquired the same satellites with those at Ublox-M8T except for GLONASS No. -1 and BDS No. 4 satellites. The comparison of the acquired satellite C/N0 showed a mean difference of 0.9 dB.

To analyze this in more detail, C/N0 errors were summarized by satellite system, which are listed in Table 3. As shown in Table 3, a difference of C/N0 in GPS L1 C/A indicated that the USRP was approximately 0.7 ~ 0.8 dB higher than that of Ublox-M8T. On the other hand, GLONASS G1 and BDS B1I systems showed that the USRP was approximately 1 ~ 2 dB lower than that of Ublox-M8T. The reason for the above result is due to attenuation of the

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carrier-to-noise power ratio caused by band overlapping of BDS B1I and GLONASS G1 around 1 MHz (Ziemer & Tranter 2006).

5. CONCLUSIONS

In this paper, a system that can collect GPS L1 C/A, GLONASS G1, and BDS B1I signals with single front-end receiver was implemented using a universal software radio peripheral (USRP) and its performance was verified. Hardware was configured to collect GNSS signals using the USRP and external oscillator was added. In addition, a value of optimum LO frequency was selected to sample signals from three systems without degradation with a low sampling rate as much as possible. As a result, a plan of frequency of IF band that minimized the effect of three systems using LO frequency of 1584 MHz was set up and multi GNSS signals can be collected by sampling 50 Msps.

The collected signals were demodulated with baseband signals through signal acquisition of parallel code space search mode and signal track process consisting of PLL and DLL and C/NO was estimated. The comparison result of C/N0 between the signal collection system using the proposed method and commercial receiver showed that the proposed system had 0.7 ~ 0.8 dB higher than that of commercial receiver for GPS L1 C/A signals and 1 ~ 2 dB lower than that of commercial receiver for GLONASS G1 and BDS B1I. The above results verified that GNSS signals of the three different systems collected via a single USRP were normal signals. In the future, the multi GNSS signal collection system based on USRP designed and implemented in this paper will be evolved into a receiver that has reconfiguration channels by combining the SDR.

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